

II) Experimental Design

Theory and simulations



Great promise of significant scientific and technological achievements!

How to realize this promise?

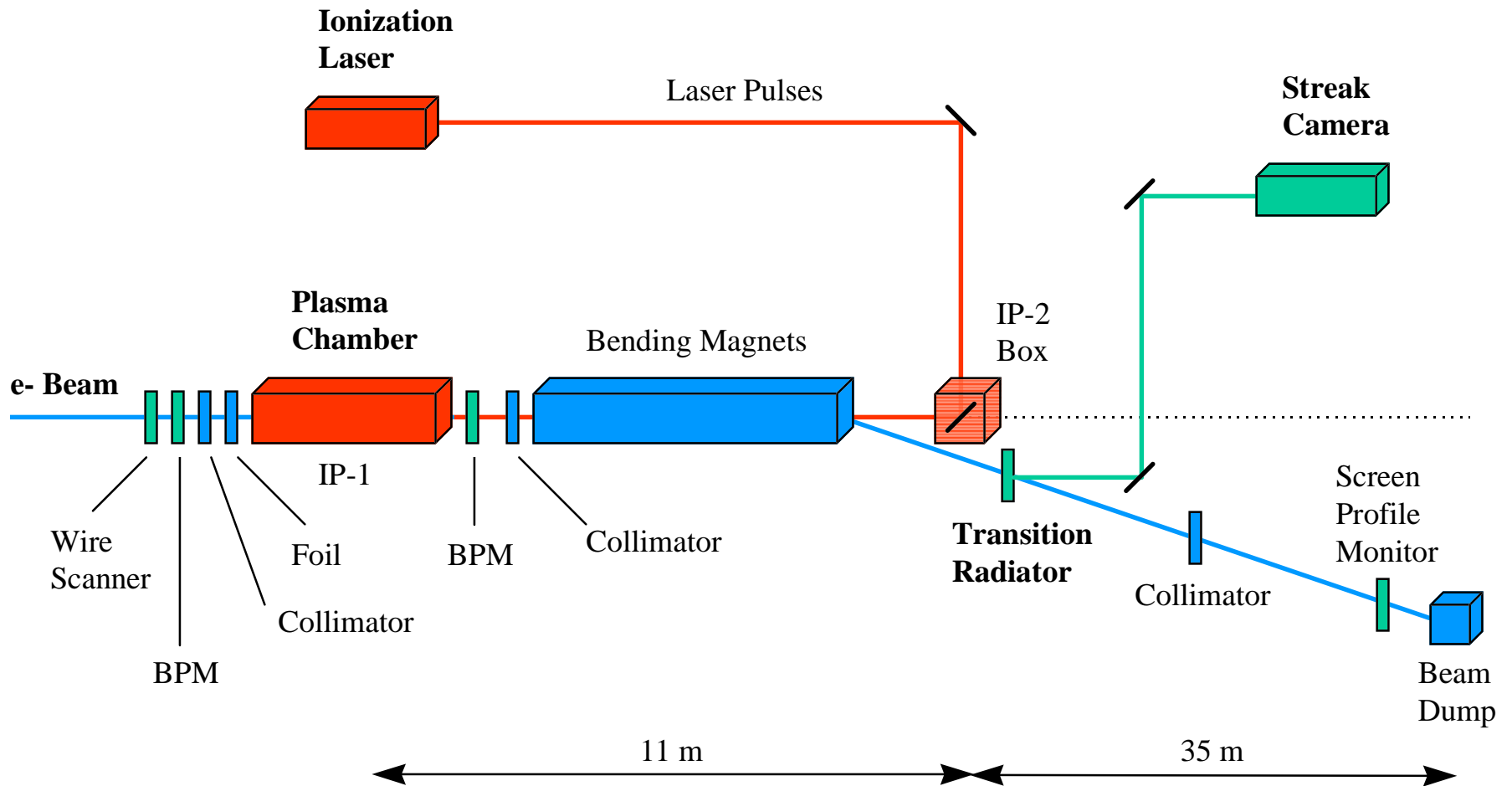
Design of experiment:

- A) **Beam system**
- B) **Plasma system**
- C) **Diagnostic system**

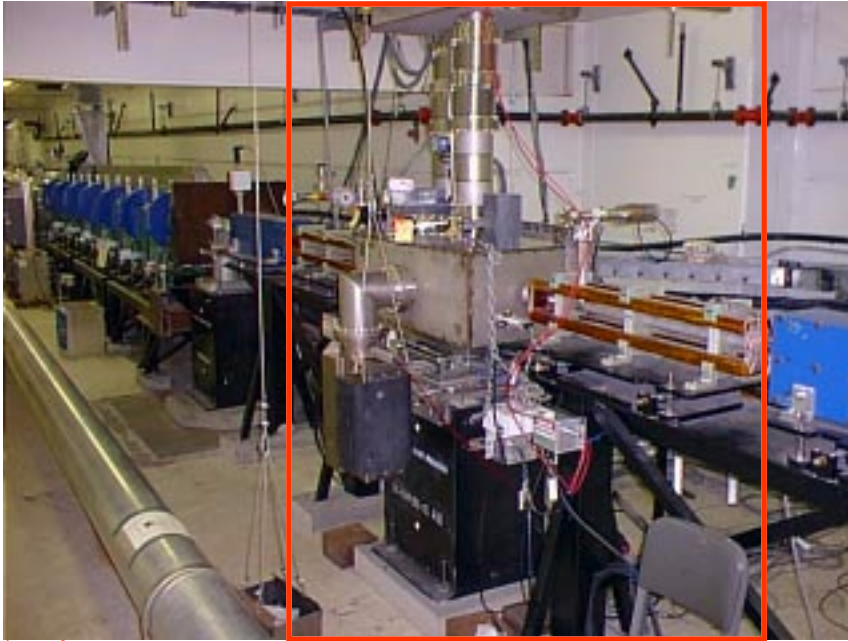
Overview! Many more details in proposal.

Schematic Layout of Experiment

Beam system -- Plasma system -- Diagnostic system



PWFA experimental location



E-144 setup
replaced by
plasma
chamber

(IP-1)



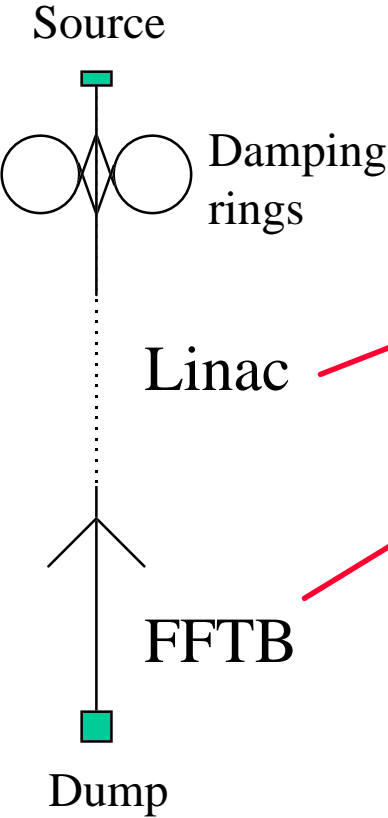
*Permanent
magnets
bend beam*

- Diagnostics (dispersion)
- Laser entry

(IP-2)

A) Beam system

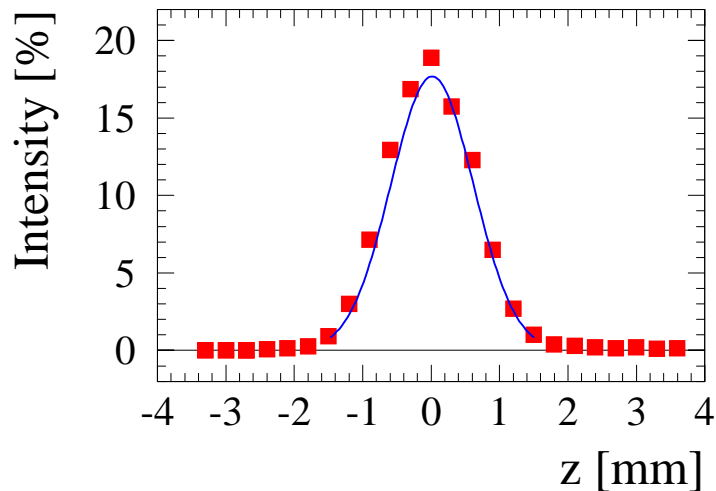
Use the SLC high current beam in the FFTB:
(parasitic to PEP-2, as now PEP-2/SLC)



Bunch intensity (e-)	3.5-4.0 10^{10}
Bunch length	0.6 mm
Beam energy	30-45 GeV
Beam rate	10 Hz
X emittance	> 60 mm-mrad
Y emittance	> 15 mm-mrad

Radiation safety and beam dump transport OK.

Longitudinal bunch shape:



Measured data

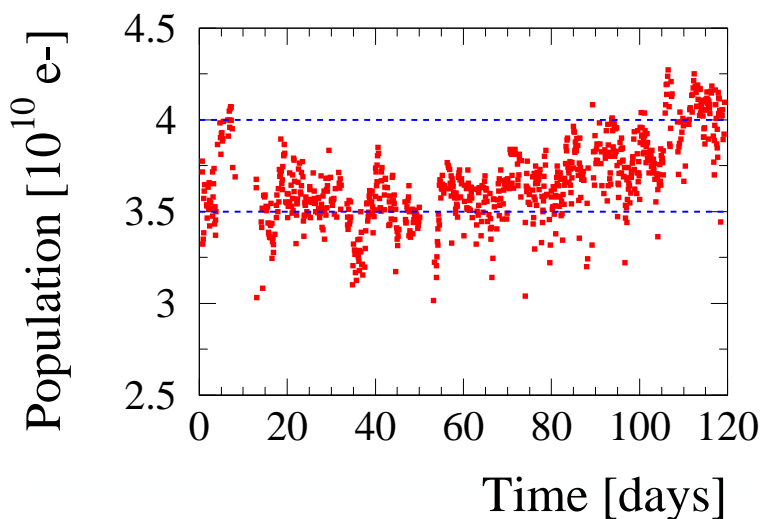
R. Holtzapple SLAC-487

Gaussian fit:

$$\sigma_z = 0.6 \text{ mm}$$

Measured bunch distribution used for proposal!

Beam current:



FF current

SLC run '96

Target currents
routinely achieved

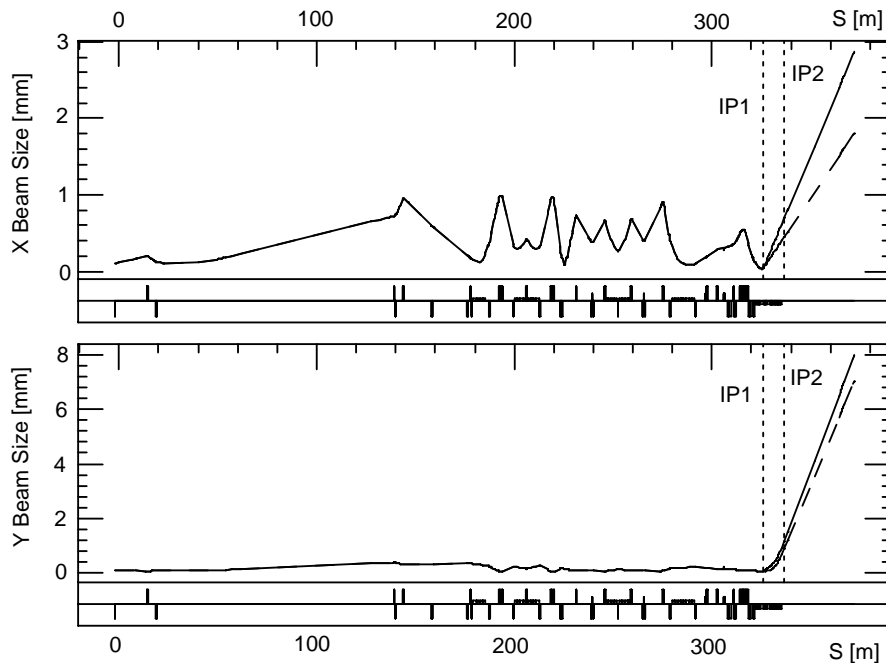
No serious emittance/background constraints!

Beam transport to plasma chamber:

Energy spread: $\sigma_E/E = 1\%$

(for 30 GeV BNS; 45 GeV performance is 0.15 %)

With $\gamma\epsilon_x = 60$ mm-mrad
 $\gamma\epsilon_y = 15$ mm-mrad we expect at IP-2:



Round beam ($\sim 40 \mu\text{m}$ times $\sim 40 \mu\text{m}$)

Beam jitter: 50 % of beam size $\rightarrow 20 \mu\text{m}$

Beam system performance *uncritical!*

30 GeV beam issues:

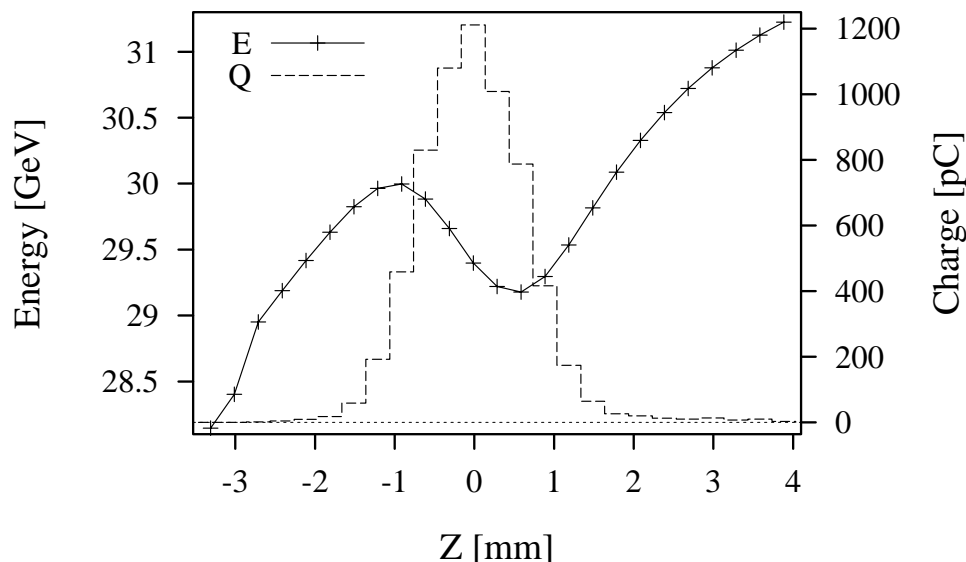
a) **Dumpline:** Re-adjust permanent dumpline magnets to 30 GeV.

Discharge two magnets.

b) **BNS:** RF has twofold purpose:
1) Energy gain.
2) Control of energy spread (BNS).

Structures stay, but wakefield compensation in the last third of the linac is not possible!

Solution for 1% final energy spread was found with RF phases of **30/-45.5 degrees**.



B) Plasma system

(design by C. Joshi et al, UCLA)

Requirements:

Length = 1-1.5 m

Density = $10^{14} - 10^{15} \text{ cm}^{-3}$

Density variation < 25% / m

Minimize impact ionization
electron beam scattering



Singly ionized Lithium plasma

($E_i = 5.9 \text{ eV}$)

m-long lithium vapors have been produced in heat pipes for atomic physics and spectroscopy experiments

Required vapor pressure: 10-30 mTorr

Lithium must be heated to 550-600 °C.

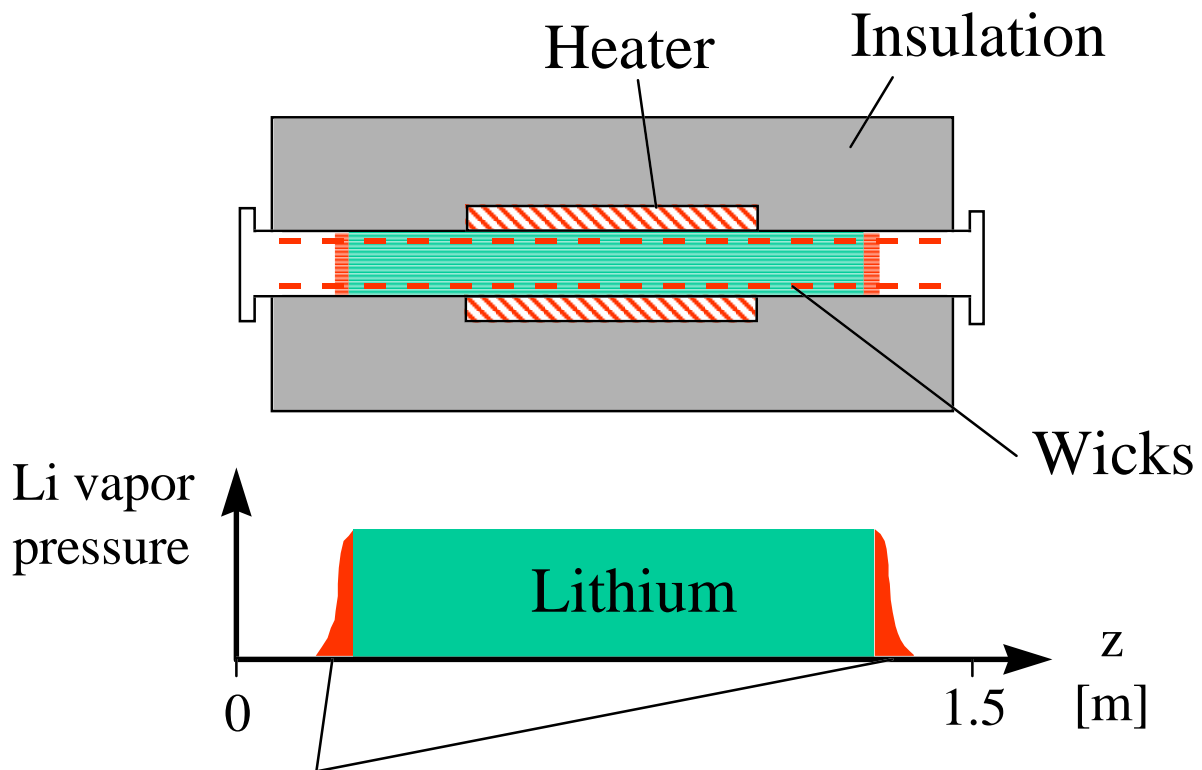
Schematic layout

Seal Lithium vapor with Helium buffer gas:

Lithium can only exist as high pressure vapor in **heated region**.

Pressure balance requires that **Helium** moves into **colder region**.

Lithium is completely sealed:



Boundary layers ~ 10 cm

Lithium vapor is homogeneous and adjustable in pressure and length.

Ionization laser

Frequency quintupled Nd:yag laser:

Repition frequency	10 Hz
Wavelength	1 μm ($h\nu = 5.9 \text{ eV}$)
Energy	500 mJ
Pulse length	$\sim \text{ns}$

Electron-ion equilibration time:

$\sim \mu\text{s}$

Cold plasma: Transverse expansion can be neglected.

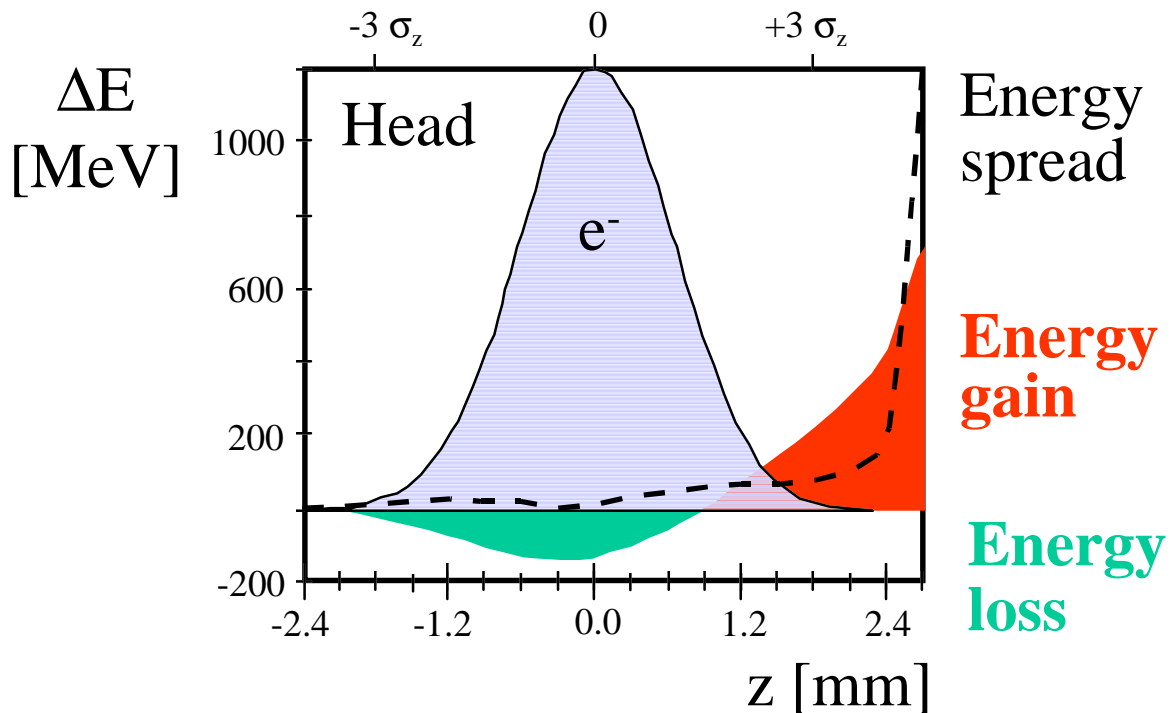
- Relatively simple, stand-alone laser system.
- Timing is non-critical.

C) Diagnostic system

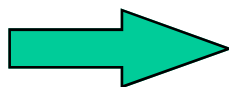
Requirements: Diagnose energy change $\Delta E(z)$ along the bunch.

Distinguish transverse and longitudinal phase space.

Simulation (1ps slices):

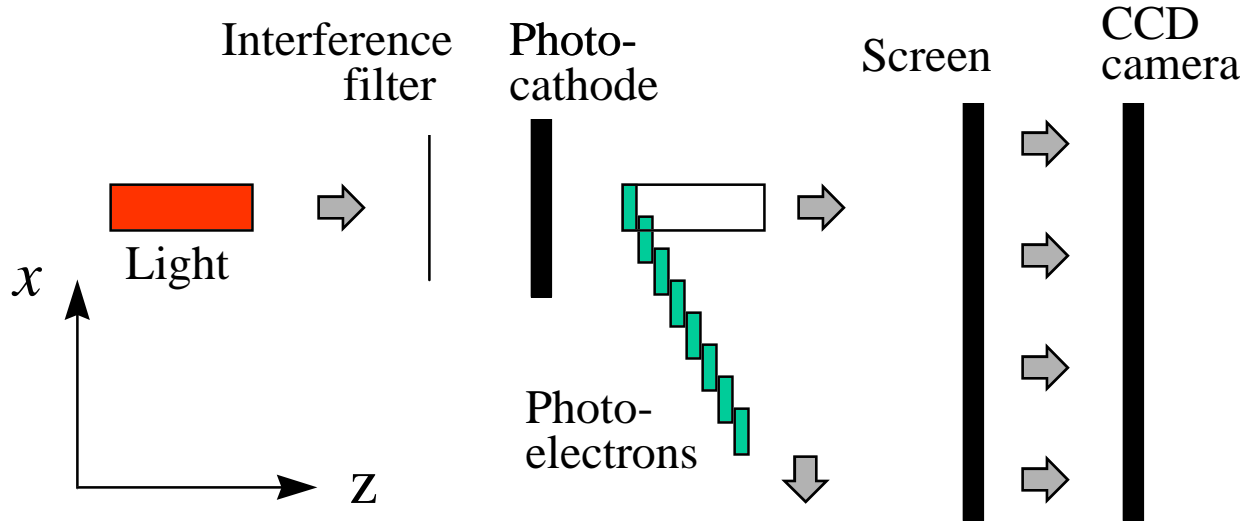


Time-resolved measurement with ~ 1 ps time resolution and good sensitivity.

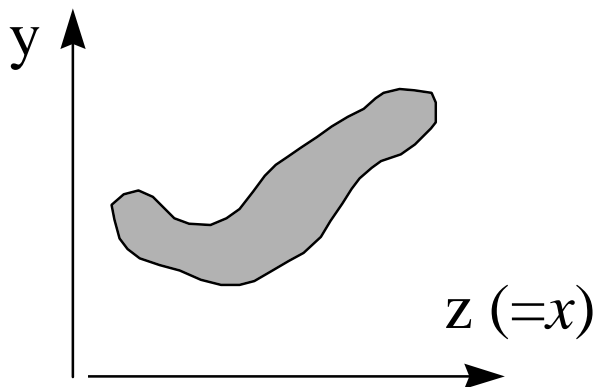


Streak camera
in dispersive region

Streak camera



Convert z (= time) into x position. Final picture:

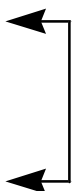


Obtain:

- $Q(z)$
- $y(z)$ or $x(z)$
- $\sigma_y(z)$ or $\sigma_x(z)$

SLAC streak camera (SLC experience):

Intrinsic resolution:	0.9 ps
Chromatic resol.:	0.5 ps
Total resolution:	1.0 ps (= 0.33 mm)
Charge resolution:	$< 10^8 e^-$



Dispersive location

Dispersion $\eta_y =$ Energy sensitivity of trajectory y

$$\Delta y = \eta_y \cdot \frac{\Delta E}{E}$$

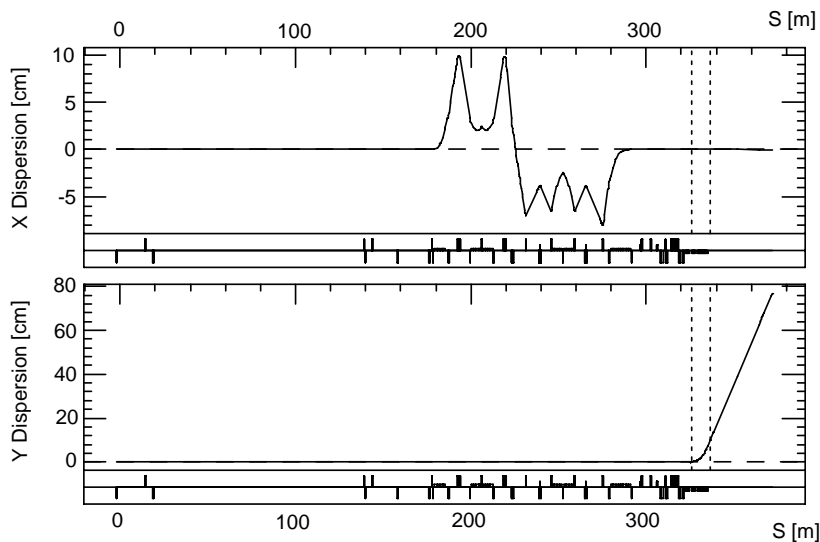
η_y known

measure $\Delta y(z)$ (plasma on/off)



$\Delta E(z)$

Use “natural” dump line vertical dispersion:



Measurement resolution (dispersive change vs. divergence blow-up) constant after IP-2.

IP-2: $\Delta y = 330 \mu\text{m}$ for $\Delta E = 100 \text{ MeV}$

Horizontal plane:

No change expected if no transverse plasma effects

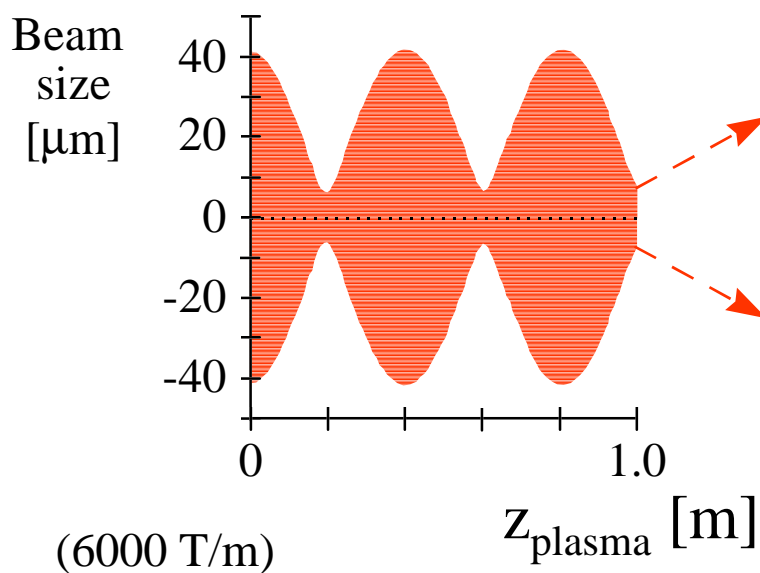
Transverse plasma effects

β -functions at IP-2: 1.1/1.7 m (x/y)

β of plasma channel: < 0.13 m



Large β mismatch!

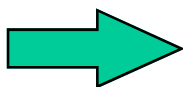


No focusing
downstream



Beam blows
up with beam
divergence +
dispersion (y)

Minimize divergence at plasma exit!

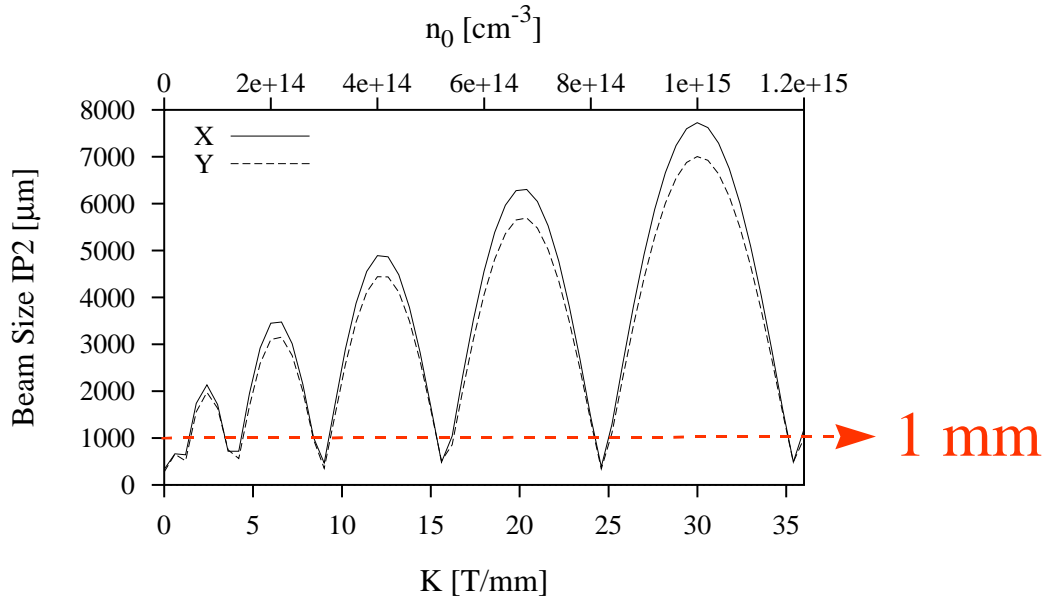


Phase advance is adjusted to be
multiple of 2π for bulk of bunch.

Plasma transparent for transverse beam dynamics!

IP-2 measurement

Beam size of 1 ps slice vs. plasma density (K)



Minimal divergence → Beam size ~ 0.5 mm

OK

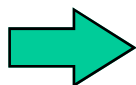
X and Y behave the same transversely:

X-plane (no dispersion)

Study and understand transverse plasma effects

Y-plane (dispersion)

Transverse + longitudinal effects



Important redundancy!

Other diagnostics

Beam: Up- and downstream BPM's
Upstream wire scanner
Screen profile monitor

Laser: Up- and downstream alignment
fluorescer

Plasma: Longitudinal density profile
measurement (laser)

Beam to laser alignment:

Requirement: $\sim 100 \mu\text{m}$ at up- and down-
stream alignment
points.

Plasma diagnostics:

Longitudinal density profile measurement.

Without beam: Calibrate plasma density/length
versus gas/heating parameters.

Summary

Experimental issues were studied in detail:

- A) Beam system: **Linac beam performance non-critical** at 30/45 GeV, assuming well-established SLC experience.
- B) Plasma system: **Conservative plasma source design** developed. Prototypes built and being tested. Large expertise at UCLA.
- C) Diagnostic system: **Consistent strategy for measuring** transverse and longit. plasma wakes in detail. Important redundancy.

Confident to measure plasma-wakefield acceleration of 1 GeV/m!

(3 times 3 weeks beam time)